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MINERAL COMPOSITION OF THE FUSION CRUST AND ALSO THE METEORITIC AND METEORIC DUST OF THE SIKHOTE-ALIN METEORITE

V. D. Kolomenskiy and I. A. Yudin

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MINERAL COMPOSITION OF THE FUSION CRUST AND ALSO THE METEORITIC AND METEORIC DUST OF THE SIKHOTE-ALIN METEORITE

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ABSTRACT. A mineralogical investigation of the minerals was performed. It is found that the main mineral of the outer zone of the Sikhote-Alin meteorite fusion crust is oxymagnetite. The fusion crust consists of an outer zone and an inner zone.

In 1952 one of the authors (I. A. Yudin) obtained from the Meteorite Committee of the USSR Academy of Sciences (METC) one sample 75 g in weight with a fusion crust and three samples with meteoritic and meteoric dust of the Sikhote-Alin meteorite for the purpose of a mineralogical investigation of the fusion crust, the meteoritic, and meteoric dust of the Sikhote-Alin meteorite [1, 3, 4, and others]. /59*

Later in 1954 METC transmitted several more small pieces of the fusion crust of the Sikhote-Alin meteorite, part of which were subjected to x-ray analysis and part of which went into the preparation of polished thin sections.

I. A. Yudin carried out the mineralogical investigation of the minerals. The x-ray investigations were carried out in the x-ray laboratory of the V. D. Kolomenskiy Leningrad Mining Institute.

THE FUSION CRUST

The meteorite's fusion crust has been established in the course of the microscopic investigation as being 0.1 - 1 mm thick. On the basis of its

*Numbers in the margin indicate pagination in the original foreign text.

mineralogical composition and structure the fusion crust is subdivided into two zones, namely, an inner zone and an outer zone.

The outer zone consists of the mineral oxymagnetite with a small amount of iocite and rare grains of nickel-iron. The boundary between the inner and outer zones is sharply expressed, sometimes rectilinear, and forms in places protruberances and recesses in the form of small inlets (Figure 1). The structure of the outer zone of the fusion crust is microporous. Pores 2 - 8 μ in diameter are observed. The number of pores in the outer zone of the fusion crust varies from several percent to 10 - 15%.

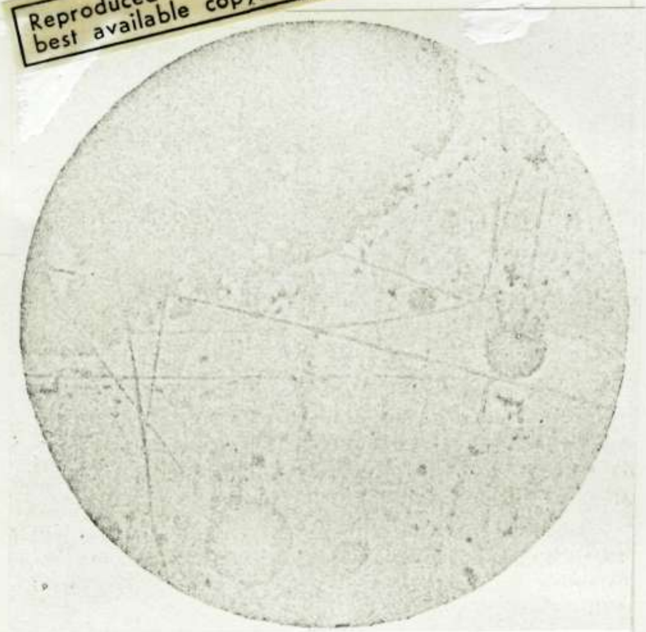

Figure 1. The inner (white) and outer (gray) zones of the fusion crust of the iron meteorite Sikhote-Alin. Gray is iocite, white is nickel-iron, and black denotes the pores. Reflected light; 600 X.

As shown by the x-ray analysis, oxymagnetite is the principal mineral making up the outer zone of the fusion crust. Iocite is encountered in regions at the boundary with the inner zone. The average value of the cell edge for oxymagnetite [a = 8.382 kX(1)] is noticeably lower than for magnetite of the normal composition $Fe''Fe_2'''O_4$, which has a = 8.396 kX. This decrease in the dimensions of an elementary cell of magnetite from the fusion crust is associated, as V. I. Mikheyev [6] has shown, with /60
the replacement of double-valency iron in the tetrahedra of the magnetite structure by tri-valent iron. The formula of magnetite from the fusion crust can be written as follows: $(Fe''_{1-x}Fe'''_{2/3x})Fe'''_2O_4$. Based on

(1) kX = 1.00202 Å.

the decrease of the cell edge from a $\approx$ 8.396 kX for normal magnetite to a $\cong$ 8.382 kX for the magnetite of the fusion crust, one can assume that x $\cong$ 0.2, i.e., the magnetite from the fusion crust is an intermediate member of the magnetite series $Fe''Fe'''_2O_4$ — namely, maggemite, $Fe''_{2/3}Fe'''_2O_4$ [8].

Iocite (FeO) is observed in the fusion crust in an insignificant amount at the boundary with the nickel-iron and is distinguished from the oxymagnetite in the course of diagnostic etching by chemical reagents. The color of the mineral is gray, just as is oxymagnetite. It is isotropic. HCl acts positively (the mineral darkens), and effervescence is observed from the presence of HNO_3.

The x-ray investigations of iocite gave an average value for its cell edge of a = 4.284 kX.

Iocite was synthesized by I. A. Yudin in the Metal Technology Laboratory of the Sverdlovsk Mining Institute. Small pieces of the meteorite in a mixture with magnetite powder were placed in an iron tube 8 mm in diameter and 23 mm in length. Iron plugs were inserted from both ends of the tube, and they were forced in at a pressure of 120 atm. This mixture was kept in a muffle furnace at a temperature of 1000° for 29 hours. Iocite was obtained at the edges of the nickel-iron as a result of the experiment performed (Figure 2)[2].

Nickel-iron is encountered in the outer zone in the form of rare fine isometric grains or in the form of small spheres near the boundary of the inner zone of the fusion crust. The grain sizes reach hundredths of a millimeter. Sometimes the grains of nickel-iron in the outer zone when isolated form bands with a width up to 0.1 mm, running parallel to the inner zone of the fusion crust. The x-ray analyses of the nickel-iron of the /61

(2) Iocite can be obtained by the oxidation of iron (without the addition of magnetite dust) (Editor's remark).

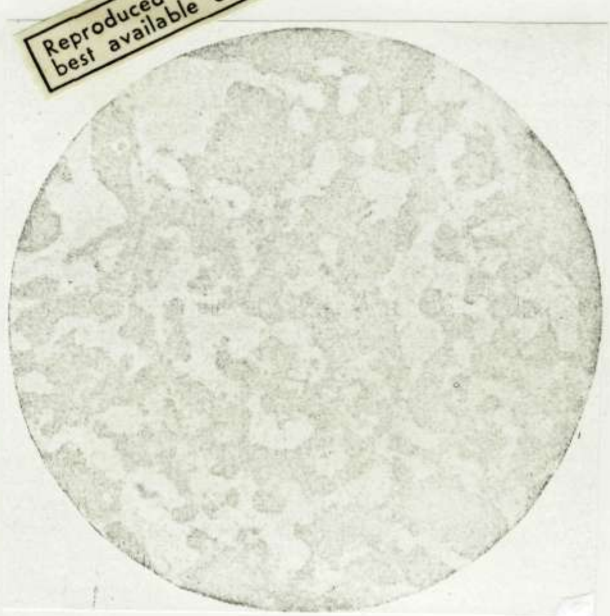

Figure 2. Structure of the replacement of nickel-iron (white) by iocite (wüstite) obtained by an artificial method. On the photograph iocite is gray. Reflected light; 600 X.

Sikhote-Alin meteorite's fusion crust showed that it consists of kamacite, whose cell edge has an average value a = 2.863 kX.

The inner zone of the fusion crust consists of nickel-iron with rare drop-like grains of iocite. The number of pores in it is less than in the outer zone. Borders of iocite have developed in some pores along the periphery (Figure 1).

The results of the interpretation of the x-ray photographs of the Sikhote-Alin meteorite's fusion crust are given in Table 1.

In an x-ray investigation of the sample of the Sikhote-Alin meteorite's fusion crust, many weak lines are revealed which arise due to mineral admixtures in addition to the bright lines corresponding to oxymagnetite.

The relative intensity of the lines and the interplane distances for α and β-radiation of an iron anticathode are indicated in the second, third, and fourth columns of the table for the given sample.

Of the 42 lines on the Debye-gram of the given sample, 25 lines refer to oxymagnetite. The lines of kamacite and iocite are completely and positively ascertained. Kamacite and iocite explain in addition 14 more lines of the 17 which are not due to oxymagnetite. Of the remaining three lines which are not interpreted, the eighth line with an intensity of 2 is of greatest

TABLE 1. INTERPRETATION OF THE MATERIAL COMPOSITION OF A SAMPLE OF THE FUSION CRUST FROM THE SIKHOTE-ALIN METEORITE.

No.	I	$\frac{d\alpha}{n}$	$\frac{d\beta}{n}$	Magnetite				Kamacite				Iocite			
				I	$\frac{d\alpha}{n}$	hkl	a	I	$\frac{d\alpha}{n}$	hkl	a	I	$\frac{d\alpha}{n}$	hkl	a
1	4	4,85	4,40	—	—	111	8,41	—	—	—	—	—	—	—	—
2	1	4,20	3,81	1	4,21	200	8,40	—	—	—	—	—	—	—	—
3	1	3,42	3,10	—	—	—	—	—	—	—	—	—	—	—	—
4	2	(3,27)	2,96	3	(3,31)	220 β	—	—	—	—	—	—	—	—	—
5	1	3,07	2,78	—	—	—	—	—	—	—	—	—	—	—	—
6	7	2,97	2,69	6	2,99	220	8,40	—	—	—	—	—	—	—	—
7	5	(2,794)	2,532	5	(2,807)	311 β	—	—	—	—	—	—	—	—	—
8	2	2,604	2,360	—	—	—	—	—	—	—	—	—	—	—	—
9	10	2,529	2,292	10	2,541	311	8,384	—	—	—	—	—	—	—	—
10	3	2,477	2,245	—	—	—	—	—	—	—	—	7	2,47	111	4,290
11	1	2,417	2,191	3	2,428	222	8,368	—	—	—	—	—	—	—	—
12	2	(2,364)	2,142	—	—	—	—	—	—	—	—	—	—	—	—
13	1	(2,313)	2,096	3	(2,310)	400 β	—	—	—	—	—	—	—	—	—
14	2	(2,234)	2,025	—	—	—	—	4	(2,233)	110 β	—	—	—	—	—
15	8	2,141	1,941	—	—	—	—	—	—	—	—	10	2,14	200	4,282
16	7	2,095	1,899	7	2,098	400	8,380	—	—	—	—	—	—	—	—
17	8	2,024	1,835	—	—	—	—	10	2,022	110	2,859	—	—	—	—
18	1	(1,884)	1,708	2	(1,884)	422 β	—	—	—	—	—	—	—	—	—
19	3w*	(1,780)	1,614	4	(1,785)	511 β 333 β	—	—	—	—	—	—	—	—	—
20	5	1,711	1,551	5	(1,411)	422	8,384	—	—	—	—	—		—	—
21	2	(1,672)	1,516	—	—	—	—	—	—	—	—	—			

TABLE 1. INTERPRETATION OF THE MATERIAL COMPOSITION OF A SAMPLE OF THE FUSION CRUST FROM THE SIKHOTE-ALIN METEORITE.

No.	I	$\frac{d\alpha}{n}$	$\frac{d\beta}{n}$	Magnetite				Kamacite				Iocite			
				I	$\frac{d\alpha}{n}$	hkl	a	I	$\frac{d\alpha}{n}$	hkl	a	I	$\frac{d\alpha}{n}$	hkl	a
22	2	(1,636)	1,483	2	(1,632)	440 β	—	—	—	—	—	—	—	—	—
23	8	1,612	1,462	9	1,612	511; 333	8,374	—	—	—	—	—	—	—	—
24	1	(1,582)	1,434	—	—	—	—	2	(1,579)	200 β	—	—	—	—	—
25	7	1,515	1,374	—	—	—	—	—	—	—	—	8	1,51	220	4,286
26	9	1,481	1,342	9	1,479	440	8,377	—	—	—	—	—	—	—	—
72	3	1,433	1,299	—	—	—	—	7	1,431	200	2,866	—	—	—	—
28	1	(1,413)	1,280	2	(1,411)	531	—	—	—	—	—	—	—	—	—
29	1	(1,365)	1,237	—	—	—	—	—	—	—	—	—	—	—	—
30	4	1,325	1,201	3	1,325	620	8,381	—	—	—	—	—	—	—	—
31	5	1,291	1,170	—	—	—	—	3	(1,290)	211 β	—	4	1,293	311	4,280
32	6	1,278	1,158	5	1,277	533	8,370	—	—	—	—	—	—	—	—
33	1	1,264	1,146	2	1,264	622	8,380	—	—	—	—	—	—	—	—
34	4	1,237	1,121	—	—	—	—	—	—	—	—	2	1,238	222	4,282
35	2 w*	(1,210)	1,097	3	(1,209)	444	8,385	—	—	—	—	—	—	—	—
36	6	1,169	1,060	1	1,174	711; 551	—	8	1,166	211	2,864	—	—	—	—
37	1	(1,155)	1,047	1	(1,153)	800 β	—	—	—	—	—	—	—	—	—
38	4	1,120	1,015	4	1,119	642	8,378	2	(1,117)	220 β	—	—	—	—	—
39	8	1,091	0,989	8	1,091	731; 553	8,379	—	—	—	—	—	—	—	—
40	2 w*	1,071	0,971	—	—	—	—	—	—	—	—	1	1,072	400	4,284
41	5 w*	1,048	0,950	6	1,047	800	8,384	—	—	—	—	—	—	—	—
42	2 w*	1,013	0,918	—	—	—	—	3	1,012	220	2,865	—	—	—	—
					Average $a = 8,383$				Average $a = 2,8648$				Average $a = 4,284$		

*w - wide.

interest to us. The remaining two lines, namely, the third and the fifth, have the minimum intensity of 1°. It is possible that these still uninterpreted lines refer to a new mineral, for which there are not standards in the x-ray detector.

Data for the intensities of the lines and the interplanar distances for magnetite, kamacite, and iocite are given in columns 5, 6, 9, 10, 13, and 14, respectively [5]. /64

Symbols which reflect the two-dimensional network for the structures of magnetite, and kamacite, and iocite, respectively, are given in columns 7, 11, and 15.

Calculations of the quantity a, the cubic cell edges for oxymagnetite, kamacite, and iocite, are indicated in columns 8, 12, and 16.

The average value of the cell edge of the oxymagnetite of the Sikhote-Alin meteorite was found to be a = 8.383 kX.

The average value of the cell edge of kamacite is a = 2.864 kX.

The average value of the cell size for iocite is a = 4.284 kX.

METEORITIC DUST

Meteoritic dust consists of small fragments formed upon the meteorite's breakup at the surface of the earth.

The meteoritic dust in the investigated samples consists of small acute-angled particles of an irregular shape. The sizes of these fragments vary from several microns to 0.5 mm.

The minerals which comprise meteoritic dust are nickel-iron, magnetite, and hydroxides of iron (limonite and geothite). The main mass of meteoritic dust (up to 85% by volume) consists of fragments of nickel-iron which have been subjected to a certain extent to oxidation with the formation of minerals of the hydroxide group of iron as a result of exogenic processes.

METEORIC DUST

Meteoric dust is formed from the melted material blow off in the atmosphere from a meteoric object moving with the escape velocity, and it is also the product of the condensation of vaporized meteoric material. Meteoric dust is essentially similar in its mineralogical makeup to the outer zone of the meteorite's fusion crust. In form meteoric, dust is encountered as small spheres, pear-shaped features, and filaments [2].

Upon inspection under a binocular microscope of the sample, meteoric dust was discovered together with the meteoric dust in the form of several solidified droplets (Figure 3). /66

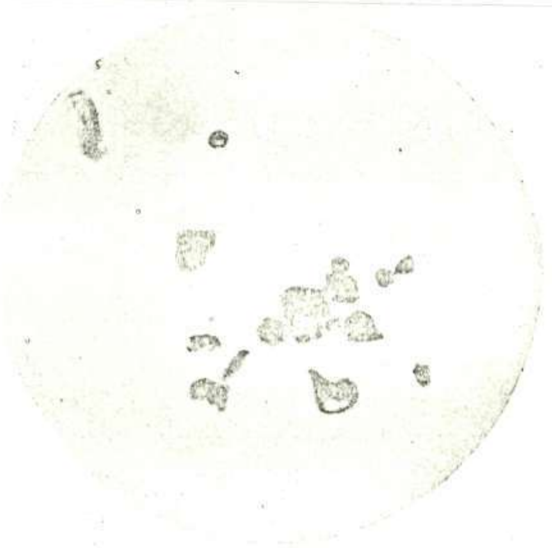

Figure 3. Meteoric and meteoritic dust; 30 X.

Upon mineralogical investigations in polished thin sections, meteoric dust is observed in the form of small spheres and pear-shaped forms. Six such features were found in the polished thin sections. The diameter of these spheres is from 0.2 to 0.04 mm. The mineral which makes up the spheres is oxymagnetite.

A sphere with a diameter of 0.2 mm has been found (Figure 4) in the center of which there is a cavity [4]. Two spheres 0.08 and

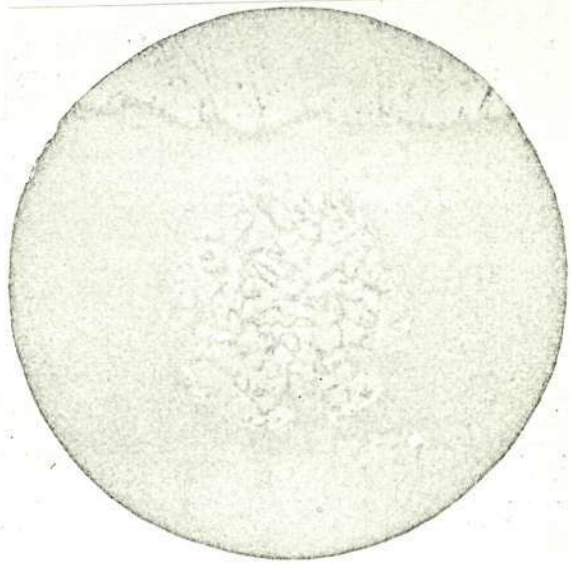

Figure 4. Oxymagnetitic sphere of meteoric dust with a cavity inside (black). Reflected light; 600 X.

Figure 5. Oxymagnetitic sphere of the meteoric dust with a granular structure. Reflected light; 600 X.

0.06 mm in diameter were discovered in another part of this same polished thin section. Both spheres consist also of oxymagnetite of microgranular structure. The grain sizes of the oxymagnetite which makes up one of the spheres are 3 - 8 μ. The grains are of an isometric shape (Figure 5).

CONCLUSION

It is possible to draw the following conclusions as a result of the investigations which have been carried out:

1. On the basis of the data from the x-ray investigation, the main mineral of the outer zone of the Sikhote-Alin meteorite's fusion crust is oxymagnetite. The formula $(Fe^{\cdot\cdot}_{1-0,15}Fe'''_{\frac{2}{3}-0,15})Fe'''_2O_4$ has been established for it.

2. The fusion crust of the Sikhote-Alin iron meteorite consists of two zones, an inner zone and an outer zone. The outer zone consists mainly

of the minerals oxymagnetite, iocite, and rare grains of nickel-iron, and the inner zone consists of iocite and nickel-iron.

3. The meteoritic dust consists both of nickel-iron and of magnetite.

4. The meteoric dust is encountered in the form of dense and cavity-filled spheres and also of filaments; the composition corresponds to the mineral oxymagnetite.

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